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Heavy Metal Pollutions and Its Associated Ecological Risks in Lagos Lagoon Sediments, South-western Nigeria

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Authors' contributions

This work was carried out in collaboration amongst all the four authors. Authors AGE and OKI designed the study, wrote the protocol, managed the literature search, author PSO wrote the first manuscript with the assistance from authors AGE, OKI and OPO. Author OPO carried out the total organic carbon content analysis (TOC) and interpretations. All four authors read and approved the final manuscripts.

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ABSTRACT

This study investigate the origin of heavy metal pollution and its associated ecological risks to the surrounding aquatic ecosystems in the Lagos Lagoon. Sediments samples from twelve selected stations, that covers the; Southern, central and North-Eastern segments of Lagos Lagoon were analysed for levels of selected heavy metals i.e, Fe, Cu, Mn, Zn, Pb, Cr and Ni over a 3 month

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period. Six Pollution indices were applied in assessing the pollution status of heavy metals in sediments. These comprised; three single pollution indices (The Contamination Factor, Ecological Risk Factor and Enrichment Factor) and three integrated pollution indices (Average Pollution Index, Ecological Risk Index and Nemerow Pollution Index). Heavy metal concentrations in the Lagos Lagoon sediments range from; Ni (Bdl-17.55 mg/kg), Mn (12.5-1180.25 mg/kg), Pb (Bdl-27.04 mg/kg), Zn (Bdl-543.33 mg/kg), Cu (Bdl-35.55 mg/kg), Cr (Bdl-220.53 mg/kg) and Fe (832.64-19722.80 mg/kg) respectively. The respective nutrients values in the sediments ranges are; nitrate (0.10-1.16 mg/kg), phosphate (1.61-6.61 mg/kg), silicate (1.77-63.55 mg/kg), total organic matter (0.27-4.35 mg/kg) and total organic carbon (0.15-2.45 mg/kg).The average metal concentrations were compared with its respective background values, using the Average shale contents (ASC) thus; Zn, Pb and Mn exhibited elevated concentrations above the ASC at; Iddo, Okobaba, Ijora and Majidun segments of Lagos Lagoon and are moderately to severely contaminated. It also demonstrates a dominant anthropogenic origin to all analysed heavy metals with the exception of Iron. However, the integrated pollution indices affirmed a low ecological risk index to the aquatic ecosystem of the Lagos Lagoon. The calculated Total Organic Carbon (TOC) displayed a high percentage values in the aforementioned stations and correlated significantly with nitrate concentrations in the sediments of Lagos Lagoon. The Nemerow pollution index revealed that the heavy metals conditions in the Lagos Lagoon sediments are in a precautionary state. This call for a quick and efficient control measures to be put in place to safeguard the aquatic biota in the Lagos Lagoon.

Keywords: Waste water discharge; aquatic ecosystem; Lagos Lagoon sediments; heavy metals; below detection limits (Bdl); pollution indices; total organic carbon; precautionary state.

1. INTRODUCTION

Sediments act as important repositories for various pollutants such as; pesticides and heavy metals, it also plays a significant role as sensitive indicators for contaminants monitoring in aquatic ecosystems. Although, it provides habitats for many aquatic organisms, most have undergone contaminations with various kinds of hazardous and toxic substances. They are therefore, considered to be an important carrier as well as a sink for heavy metals in the hydrological cycle [1,2]. Waste materials including; organic and inorganic chemicals, terrestrial runoff and leachates originating from numerous urban, industrial and agricultural activities eventually accumulate in sediments. These, had often led to the accumulations of heavy metal emissions from anthropogenic sources into river and ocean sediments [3,4]. Additionally, many metals associate readily with particulates [4]. The tremendous growth of human and industrial population in Lagos metropolis in the past two decades, coupled with, increase in waste and domestic discharges are the potential sources of heavy metals accumulations in Lagos Lagoon. The aforementioned criteria are human-induced, and have contributed to heavy metals enrichment from local sources such as; discharges from smelters (Cu, Pb, Ni), metal based industries and electroplating (Zn, Cr, Cd), paint and pigments (Cd, Cr, Cu, Pb, Zn, Hg and Se), and petroleum spills (As, Pb) [5]. Most of the particulates associated heavy metals is either adsorbed or co-precipitated with; carbonates, oxy-hydroxides, sulphides, and clay minerals [6].

Different methods have been developed for the assessment of heavy metal risks in Lagos Lagoon sediments; sediment enrichment factor, geoaccumulation index, contamination factor, contamination degree, pollution load index and others [7-9]. However, there is a paucity of information in the potential ecological risk status of Lagos Lagoon sediments, hence, the Potential ecological risk index and Nemerow Pollution index were adopted to address this. The former, is the only method that considers both heavy metal concentrations and toxic response factors, while the latter had the strictest ranking among the contamination indices, it evaluates the potential health and safety status of sediments, arising from heavy metals enrichment [10]. This study analyse the concentration of; Iron, chromium, copper, lead, zinc, manganese and Nickel from bottom sediments of twelve selected stations in Lagos Lagoon, with a view to identifying the; source of heavy metal pollution and its ecological risks implications to the aquatic biota. This will provide policy makers, resource managers as well as the public with the systematic methods that can inform decision making for water source security.

1.1 Enrichment Factor (EF)

This serves as a means of identifying and quantifying human interference with global elemental cycles, [11] by utilizing geochemical normalization to access sediment contamination. In geochemical studies, immobile element nominalization is a common practice in grain-size effects and dilution correction by sedimentary phases such as; carbonates and silica. It also assesses possible elemental source and the possible anthropogenic impacts in sediments of the selected stations in Lagos Lagoon. EF values in the ranges 0.5 to 1.5 suggested that the trace metals sources might be entirely from crustal materials or natural weathering process, while, EF values > 1.5 suggested that a significant portion of trace metal was delivered from non crustal materials or non natural weathering processes (equation1).

$$\frac{T\ \text{sample}\ /\ \text{Fe sample}}{T\ \text{(background)}/\text{Fe(background)}} \quad (1)$$

Where *T* sample is trace element concentration in the sample, *T* background is trace element concentration in shale (average shale content)

1.2 Contamination Factor (CF)

Is calculated as the ratio between the sediment metal content at a given station and the background concentration levels.CF is stated in equation 2.

$$CF = C/Cn \quad (2)$$

Where CF = Contamination Factor; C = mean concentration of each metal in the sediments; Cn=background value: The CF modified by [12] showed the following classes: CF<1, low contamination, 1<CF<3, moderate contamination and 3<CF<6, considerable contamination.

1.3 Single Index of Potential Ecological Risk Factor (Eir)

Accumulating coefficient of sediments from 12 stations (Table 1) were computed and applied to indicate the accumulating status of heavy metals in sediments from each sampling stations. The method was developed by [12]. The Eir of heavy metals across the stations can be computed via equation 3.

$$E^i r = T^i_f * CF \quad (3)$$

CF = contamination factor of heavy metals

Ti_f-: The toxic response factors of element i (which reflects its level of toxicity and its bio-organisms sensitivity) for common heavy metals: Cu, Pb, Zn, Cr, Ni and Mn are: 5, 5,1,2,5 and 3 respectively [13].

1.4 Integrated Index of Pollution

This involves taking the whole contamination indices as an entity. It gives a summary of the pollution assessment of the selected stations. Three pollution indices were considered on the integrated pollution index.

1.5 Integrated Potential Ecological Risk Index

RI is calculated as the sum of all risk factors for heavy metals in sediments across the stations. The degree of ecological risk caused by heavy metal in sediment is calculated as stated in equation4

$$RI = \sum_{i=1}^{m} E_r^i \quad (4)$$

$E^i r$ = Single pollution index

The following terminologies were used for the Potential Ecological Risk Index and Single index of ecological risk factor (Eir)

E^i_r <40 or R_i <150 Low ecological risk for water body

40≤ E^i_r <80 or 150≤R_i<300 Moderate ecological risk for water body

80≤E^i_r<160 or 300≤E^i_r<600 Considerable ecological risk for water body

160≤ E^i_r <320 or 600≤R_i Very high ecological risk for water body

1.6 Average of Pollution Index

Average of pollution index (PIAvg) can be defined using Equation (5).

$$PI\ avg = \frac{1}{m}\sum_{i=1}^{m} Pi \quad (5)$$

Where Pi is the single pollution index of heavy metal “i” and “m” is the count of the heavy metal species. A value of > 1.0 indicates contaminated sediments [10].

1.7 Nemerow Pollution Index

A Nemerow Pollution Index (PI Nemerow) has been widely applied to assess the quality of sediment [10] and is defined by Equation (6):

$$\text{Pi Nemerow} = \frac{\sqrt{\frac{(1\sum_{i=1}^{m} \text{Pimax})^2}{m}}}{2} \quad (6)$$

Where Pi is the single pollution index of heavy metal “i” is the maximum value of the single pollution indices of all the heavy metals and “m” is the count of the heavy metal species

Pi Nemerow < 0.7 – safety domain, 0.7 ≤ Pi Nemerow < 1.0 – precaution domain 1.0 ≤ Pi Nemerow < 2.0 - slightly polluted domain, 2.0 ≤ Pi Nemerow < 3.0- moderately polluted domain Pi Nemerow> 3.0 – seriously polluted domain.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The Lagos lagoon (3°10’E and 3°45’ E and 6°15N and 6°36’N) is a part of the continuous system of lagoons and creeks that are found along the coast of Nigeria from the border with the Republic of Benin to Niger-Delta. The geology of the Lagos area is dominated by a continuous and monotonous repetition of clayey and sandy horizons. These horizons show some lateral continuation in some places but in most parts, these lithology pinches out [14]. Twelve stations were purposely selected based on earlier works of eminent researchers on the: sources, types and pollutants load in the Lagos Lagoon (Table 1).

2.2 Methodology

2.2.1 Sampling

Sediment samples were collected from twelve sampling stations with the aid of van-veen grab. The sampling period was carried out for three months, May to July 2014, on a monthly basis at a depth of 0-30 cm and kept in black polythene bags.

2.2.2 Sample preparation and analysis

Sediment samples were air dried, disaggregated and sieved. The sieved sediments were leached with Nitric/Hydrochloric acid (1:3), aqua regia using standard digestion procedure [20]. Trace metal contents were analysed with Argillent 200 A model, Atomic Absorption Spectrophotometer (AAS).

Table 1. Sampling stations and associated anthropogenic activities

Station number / Name	Latitude	Longitude	Anthropogenic activities
1 ATC	6°25' 19.063"	3°23' 51.93"	Accidental petrole um discharge, dredging Oil and Grease, lead combustion, [15]
2 APP	6°26' 43.03"	3°22' 57.18"	Dredging(oil and Grease, spillages, ship garbage [16]
3 IJR	6°27' 41.44"	3°22' 27.97"	Residential, sewa ge and industrial effluents, oil and grease.
4 IDD	6°27' 58.96"	3°22' 56.45"	Domestic sewage disch arges, (Biodegradable organic matter, [17].
5 OKB	6°28' 57.37"	3°23' 40.98"	Wood logging, saw dust input (Biodegradable organic matter, [18].
6 UWF	6°31' 11.72"	3°24' 16.76"	Marine debris.
7 MDL/CLA	6°30' 57.12	3°26' 34.03"	Recent residen tial effluents accumulation.
8 AGB	6°33' 39.211"	3°25' 55.333"	Local dredging
9 MJD	6°35' 26.54"	3°27' 29.52"	Local dredging, dum psite/residential discharges [19].
10 IKP	6°35' 42.60"	3°28' 58.60"	Industrial efflu ents
11 IBS	6°32' 58.32"	3°28' 17.71"	Dredging
12 EGB	6°33' 20.96"	3°36' 19.60"	Thermal pollutio n, Elevated water temperature [18]

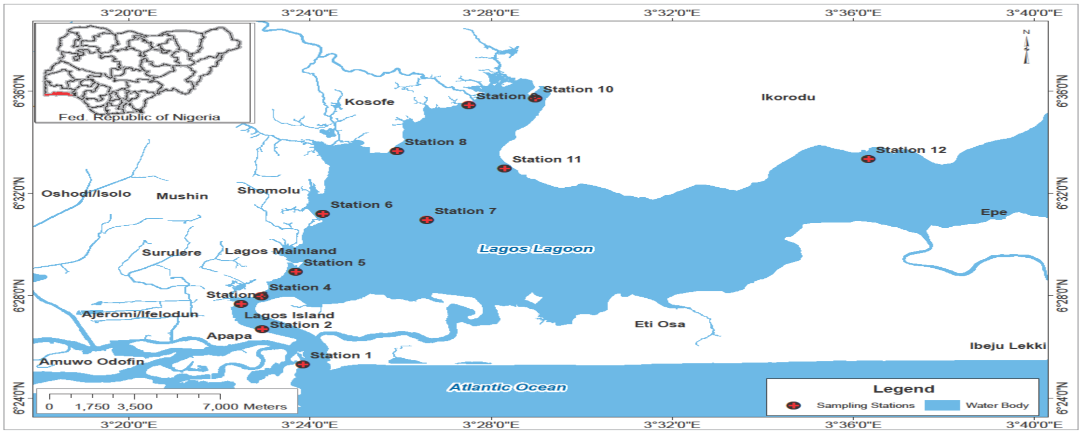

Fig. 1. Map of Lagos Lagoon showing the sampling stations

2.2.3 Determination of total organic carbon

The total organic matter was determined titrimetrically [21,22] using the procedure for measuring decomposable organic matter in the sediments. In which, sediment samples were grounded into fine powder and 1 g of each of the samples was weighed in duplicate and transferred to the 250 ml conical flask each. 10 ml $K_2Cr_2O_7$ was later added to each. 20 ml concentrated H_2SO_4 was added to each rapidly and the sediment immediately swirled the flask. The flasks were later rotated again and allowed to stand on a sheet of asbestos for about 30 mins. 100 ml of distilled water was added to each. 3 to 4 drops of ferroin indicator was added to each and titrated with 0.5 M Iron (II) ammonium sulphate. The ferrous sulphate was added to each drop by drop until the colour change rapidly from green to brownish red. A blank titration was made but without sediment. The percentage of matter of the carbon in the organic matter was determined using Equation-:

$$TOM = \frac{V * 0.3 * M * F}{W} \qquad (7)$$

V = volume of Iron sulphate used
M = molarity of Iron sulphate used
F = correction factor that account for incomplete reaction of $K_2Cr_2O_7$ with organic carbon (1.33)
0.3 = equivalent weight of carbon.

$$TOC = \frac{TOM}{1.78} \qquad (8)$$

2.2.4 Determination of nutrients in sediments

On the determination of phosphate concentration, Ammonium molybdate and antimony Potassium Tartrate, in an acidic medium were added to filtered sediment samples (APHA, 1995). The phosphate present formed Antimony-phosphor-molybdate complex. This complex was reduced to an intensely blue-coloured complex by the addition of ascorbic acid proportional to the phosphate concentration. Measurements were taken spectrophotometricaly at wavelength of 885 nm. For the measurement of Nitrate concentration, the filtered sediments samples were reduced to Nitrite by copper-cadmium reduction, the nitrite coloured reagent was determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochlorate to form a highly coloured azo dye which was measured spectrophotometricaly at 543 nm. Separate, rather than combined nitrate-nitrite values were obtained by carrying out the procedure first with, and then without the initial cadmium reduction step. The difference gives the actual values for the nitrates present and measurements were taken spectrophotometricaly at the same wavelength. Silicate and Phosphate in the sediments samples react with molybdate ion under acidic conditions to form yellow Silicomolybdic and Phosphomolybdic acid complexes respectively [23,24], Oxalic acid ($H_2C_2O_4.H_20$) and Hydrochloric acid (HCl) was added to destroy the phosphate complexes; silicate concentration in the sediment was then determined by measuring the remaining yellow colour at a wavelength of 410 nm.

2.2.5 Data analysis

Data were subjected to; Microsoft excel, 2010 descriptive tools, statistical analysis 7 analytical software and matlab, three single pollution indices; enrichment factor [25]. (Abrahim and

Parker 2008), contamination factor, Single index of Potential ecological risk factor (Eir) and three integrated pollution indices; potential ecological risk index [12], average pollution index and Nemerow pollution index [26]; were applied to access the heavy metal accumulation in the sediments. Pearson correlation coefficient and Hierarchical Cluster Analysis (HCA) were also used to identify the similarities in the selected stations.

3. RESULTS AND DISCUSSION

Comparing the observed concentration with the Average Shale Concentration (ASC) as proposed by [27], Zn, Pb and Mn, were observed to contain elevated concentration above the ASC in the Lagos Lagoon, in station such as: Iddo, Okobaba, Majidun, Ijora, and Egbin stations; an indication of human-induced effluents accumulations. These accumulations might not be unconnected with; population increase, commercial centers and industrial activities known for the generation of huge volume of liquid and solid wastes' sink to the adjourning sediments in Lagos Lagoon (Table 1).

To ascertain the source of the metal elevation in the samples, which is to determine whether they have been geogenically or anthropogenically derived, the average shale content, was taken as the geogenically derived portion. This was deducted from the measured concentrations and the resulting values converted into the percentage of the geogenically-induced portion. This revealed that for the selected metals, Ni, Mn, Pb, Zn, Cu and Cr have over 95% of their content contribution by anthropogenic sources while Fe has over 95% of its content contributed by geogenic means (Fig. 2). The implication of this is that wastewater discharged from the industrial and domestic effluents are metal laden with Ni, Mn, Pb, Zn, Cu and Cr.

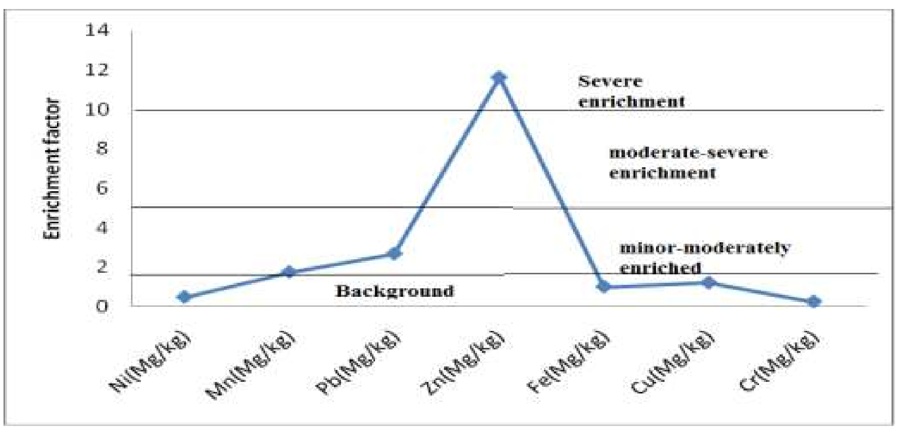

Fig. 2. Showing the enrichment factor plot

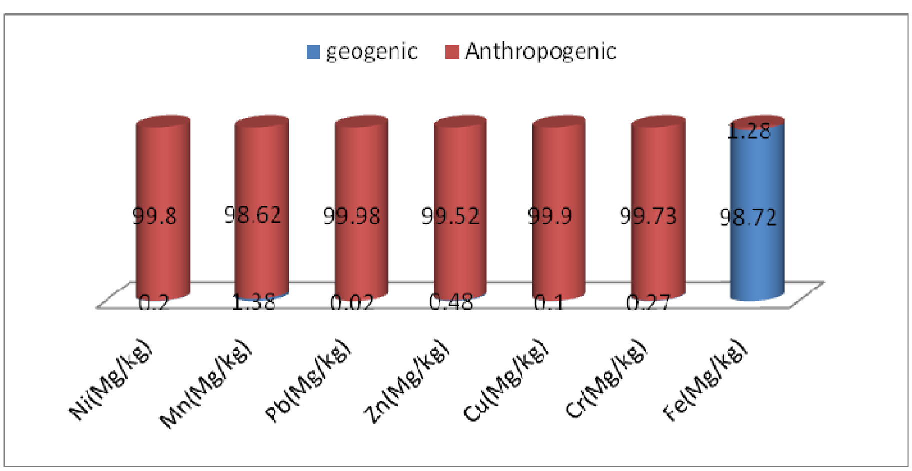

Fig. 3. Showing sources of the trace metal distributions in the study area

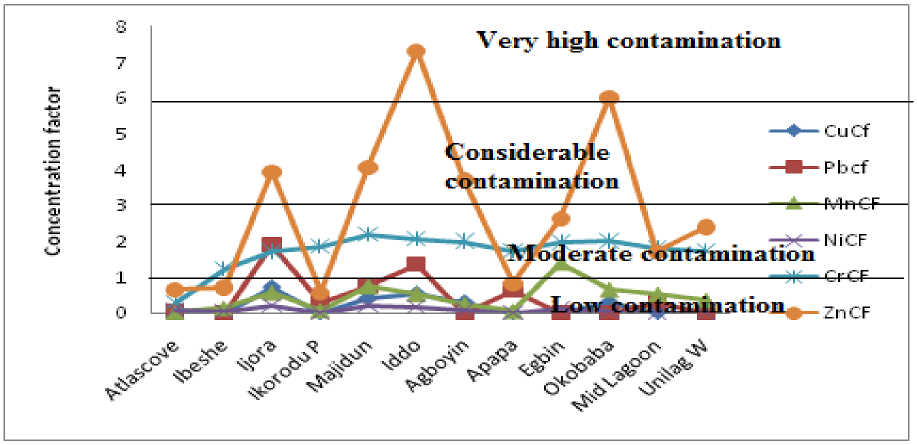

Fig. 4. Contamination factor of heavy metals in the selected stations

3.1 LPEC-Low Potential Ecological Risk for Water Body, Bdl, below Detection Level

Ecological Risk Factors were calculated for heavy metals, their toxic-response factors were available in the literature [13]. Analysis of the ecological risk factor as stated in equation 3 and 4 (Table 2), classified all the samples analyzed as having low potential ecological risk values with respect to the single, individual heavy metals ((Zn, Pb, Mn, Ni, Cu and Cr). However, the single pollution index (Pi), Table 3, demonstrated a contaminated sediment condition (Pi >1) at Iddo and Ijora stations, this is in agreement with [9]. The integrated ecological risk index also classified the sediments as having a low ecological risk values while; the Average of Pollution Index and Nemerow pollution Index classified the sediments as having low contamination and precautionary domain state respectively. The classifications by summative integrated pollution indices (Ecological Risk Index) correspond with the classifications by the Average of Pollution Index and the Nemerow pollution Index. The Nemerow Pollution Index exhibit a more stringent classification based on its safety consideration in its calculation [10], hence the bottom sediments of the selected station are at a stage at which an efficient precautionary methods are needed to be applied to prevent a serious health hazard on the aquatic ecosystem.

Table 2. Single and integrated ecological risk values of the selected stations

Location	Ei r Values for Cu	Ei r Values for Pb	Ei r Values for Mn	Ei r Values for Ni	Ei r Values for Cr	Ei r Values for Zn	Ri Integrated values	Remarks
ATC	0.046	0.15	0.04	0.55	0.62	0.67	0.34	LPEC
APP	Bdl	3.16	0.12	Bdl	3.49	0.82	1.90	LPEC
IJR	1.42	9.50	1.68	1.06	3.45	3.95	3.51	LPEC
IDD	1.08	6.76	1.55	0.88	4.19	7.33	3.63	LPEC
OKB	0.6	Bdl	1.93	0.28	4.04	6.04	2.15	LPEC
UWF	Bdl	0.005	1.05	Bdl	3.46	2.41	1.73	LPEC
MDL/CLA	ND	1.56	1.55	Bdl	3.67	1.70	2.12	LEC
AGB	0.59	Bdl	0.71	0.43	4.03	3.71	1.58	LPEC
MJD	0.84	3.84	2.2	1.10	4.41	4.09	2.75	LPEC
IKP	Bdl	1.57	0.19	0.04	3.77	0.57	1.23	LPEC
IBS	Bdl	Bdl	0.39	0.26	2.47	0.72	0.77	LPEC
EGB	0.02	Bdl	4.17	0.69	3.96	2.63	1.91	LPEC
Range	Bdl-1.42	Bdl-9.50	0.04-4.17	ND-1.06	0.62-4.41	0.57-6.04	1.97	LPEC
Mean	0.66	2.21	1.3	0.59	3.46	2.89	0.34-3.63	LPEC

Table 3. Single/integrated pollution indices and nemerow pollution indices across the selected stations

	Pi	Piavg	Pi nemerow
ATC	0.08	0.496	0.799
APP	0		
IJR	1.020		
IDD	1.002		
OKB	0		
UWF	0		
MDL/CLA	0		
AGB	0		
MJD	0.880		
IKP	0		
IBS	0		
EGB	0		
£Pi	2.980		

3.2 Total Organic Carbon and Nutrient Status of the Lagos Lagoon Sediments

Total organic carbon (TOC) is a measurement utilised to track the overall organic content of water. TOC ranged from 0.6% (Ikorodu Port) to 2.42% (Unilag waterfront). Higher water or aquatic sediments 'acidity could result to the higher TOC values (vice-versa) exhibited by; Unilag, Ijora, Agboyin, Ibese, Egbin and Okobaba sediments (Table 4). These can be linked to the numerous human-induced, domestic and industrial effluents prevalent across these aforementioned stations (Table 1). These tend to build up microorganisms' activities and reduced the aquatic dissolved oxygen concentration (DO). The nitrate and phosphate concentrations in the Lagos Lagoon sediments range from 0.10-1.16 mg/kg and 1.61-6.61 mg/kg respectively (Table 4). Low phosphate and nitrate level in most of the stations (especially at central area of the Lagos Lagoon) can also be attributed to high activity rate of microorganisms and uptake, while, higher phosphate concentration at Egbin station could be attributed to the addition of phosphate along with the land drainage and detergent rich sewage effluents. Nitrates occur in water as the end product of biological breakdown of organic nitrogen. Although not particularly toxic to fish, an excess nitrate concentration in water is often used as an indicator of poor water quality. Higher Nitrate concentration and Total organic carbon in Unilag sediments affirmed these assumptions. Silicate (Si) ranged from 1.77-63.55 mg/kg, silicate is highly essential for shell buildings to aquatic organisms. Higher silicate values were analysed in Unilag, Apapa and Majidun sediments.

Figs. 5, 6 and 7 shows the linear relationship between TOC and the nutrients concentrations in the Lagos Lagoon sediments.

3.3 Pearson Correlation Coefficient

The Pearson correlation coefficient shows that nitrate is significantly correlated with TOC ($r=0.71$, $P<0.05$), this further affirmed that nitrate forms the end product of the biological breakdown of organic matter in the Lagos Lagoon sediments (Nitrates occur in water as the end product of biological breakdown of organic nitrogen).Phosphate, silicate exhibit a weak correlation with TOC (Figs. 5-7), this shows that their accumulation is not unconnected to organic matter deposition. Detail inter-relationship between the heavy metals of the selected stations has been described in [28]. Table 5 and 6 shows the Pearson correlation rank coefficients and statistical test of the dissolved nutrients and TOC in the sediments of the selected stations in Lagos Lagoon.

Table 4. The analysed nutrients and total organic content across the selected stations

Stations	N (mg/kg)	P (mg/kg)	Si (mg/kg)	TOM%	TOC%
ATC	0.21	5.90	8.99	0.27	0.15
APP	1.16	5.31	62.55	4.31	2.42
IJR	0.75	4.75	3.71	1.96	1.10
IDD	0.38	6.61	6.74	0.76	0.43
OKB	0.74	4.68	2.45	1.88	1.06
UWF	1.16	5.31	63.55	4.35	2.45
MDL/CLA	0.15	1.61	2.38	1.88	1.06
AGB	0.74	4.68	2.45	1.88	1.06
MJD	0.19	6.61	6.74	1.28	0.72
IKP	0.10	3.22	1.77	1.07	0.6
IBS	0.15	1.61	2.384	1.88	1.06
EGB	0.75	4.75	3.71	1.96	1.10

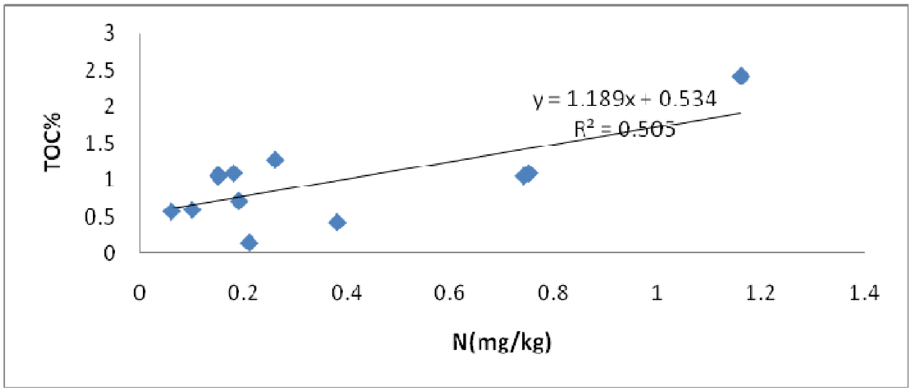

Fig. 5. Showing the linear relationship between TOC and nitrate

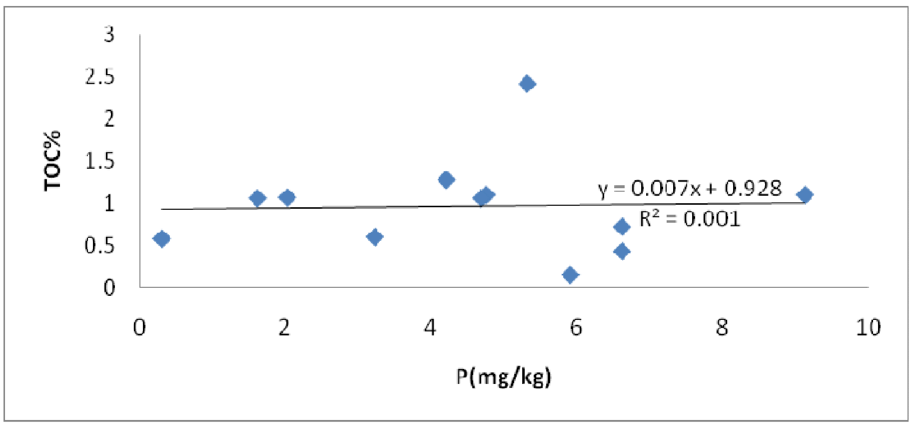

Fig. 6. Showing the linear relationship between TOC and phosphate

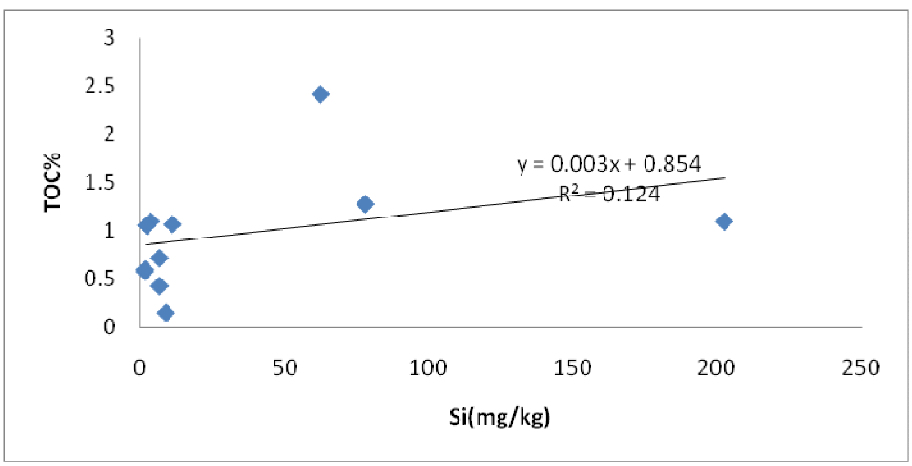

Fig. 7. Showing the linear relationship between TOC and silicate

3.4 Cluster Analysis (CA)

Hierarchical cluster analysis determines relationships and similarities among variables in their respective stations. The CA for the study area can be grouped into two; (Fig. 8), cluster1 displayed metals in stations 1(Atlascove), 8(Apapa Port), 2(Ibeshe), and 12(Unilag waterfront sediments) as having similar relationship, these can be reliably linked to the

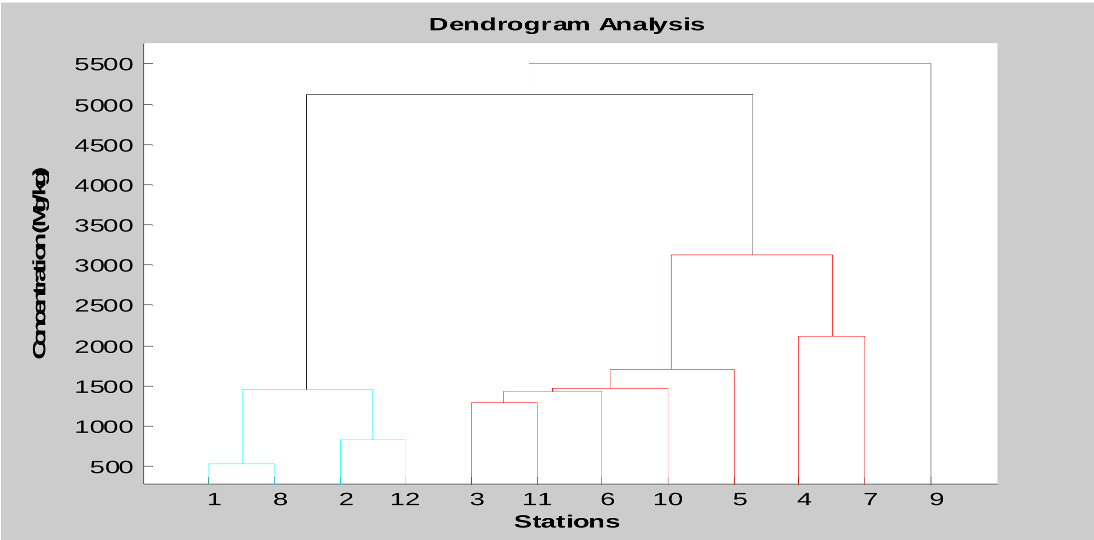

Fig. 8. Cluster relationship of the metals across the stations

anthropogenic activities such as; sand mining, oil spills and domestic/industrial effluents in the stations (Table 1). Moreover, cluster 2 displays heavy metals in stations 3(Ijora), 11(mid/central Lagoon), 6(Iddo), 10(Okobaba), 5(Majidun), 4(Ikorodu Port), and 7(Agboyin) respectively, as having a unique similarities. The cluster 2 affirmed the high CF values of; Zn, Pb and Mn concentrations in the aforementioned stations (Fig. 8), it also corroborate the high values in the calculated integrated potential ecological index ratio, (Table 2) and pollution index across the stations(Table 3).

Table 5. Pearson correlation coefficient for the dissolved nutrients and TOC

	N	P	Si	TOC
N	1.00			
P	0.24	1.00		
Si	0.007	0.59	1.00	
TOC	0.71	0.03	0.35	1.00

Table 6. Statistical test for the dissolved nutrients and TOC at 5% significance (P value)

	N	P	Si	TOC
N	------			
P	0.45	------		
Si	0.98	0.04	--------	
TOC	0.0095	0.92	0.26	-------

4. CONCLUSION

The heavy metals under investigation in the selected stations in Lagos Lagoon sediments reflected an integrated low ecological risk to the surrounding aquatic ecosystem. This is evident in its low; ecological risk index value, average pollution indices (Pi average) and the Nemerow pollution index values (P nemerow). However, the single pollution index, contamination factor and enrichment factor indices indicate; Zn, Pb and Mn to be moderately to very highly contaminated and moderately to severely enriched at; Iddo, Ijora, Okobaba, Egbin, Majidun, Ibeshe and Ikorodu stations. This affirmed the documented human-induced, domestic and industrial anthropogenic activities across the aforementioned stations.

Pearson correlation coefficient and cluster analysis reveal the relationship between TOC, nutrients and the similarities of the heavy metal pollution sources across the stations. The former reveal a significant positive correlation between TOC and Nitrate($r=0.71$, $P<0.05$), while, the latter corroborate the calculated; EF, CF, Eir and Pi.

From the six applied pollution indices, the integrated Nemerow pollution index revealed that the heavy metals conditions in the Lagos Lagoon sediments are in a precautionary state, moreover, all the analysed heavy metals exhibited a dominant anthropogenic origin with the exception of Iron. A reliable control measures is needed to be put in place to protect the aquatic ecosystems in the Lagos Lagoon.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

S/N	Station abbreviations	Meaning
1	ATC	Atlascove
2	APP	Apapa port
3	IJR	Ijora
4	IDD	Iddo
5	OKB	Okobaba
6	UWF	Unilag water front
7	MDL/CLA	Middle Lagoon / central part Lagos Lagoon area
8	AGB	Agboyin
9	MJD	Majidun
10	IKP	Ikorodu port
11	IBS	Ibeshe
12	EGB	Egbin

Concentration of heavy metals in the Lagos Lagoon sediments

	Ni (Mg/kg)	Mn (Mg/kg)	Pb (Mg/kg)	Zn (Mg/kg)	Cu (Mg/kg)	Cr (Mg/kg)	Fe (Mg/kg)
ATC	8.75	12.50	0.58	59.95	1.15	30.92	832.6
IBS	4.15	109.85	Bdl	64.78	Bdl	Bdl	2807.0
IJR	16.95	477.00	38.00	355.29	35.55	172.63	16766.4
IKP	0.60	54.80	6.28	51.68	4.56	188.70	8709.2
MJD	17.55	622.10	15.37	367.94	20.95	220.53	19722.8
IDD	14.00	440.25	27.04	Bdl	26.95	209.57	15371.6
AGB	6.85	199.65	Bdl	334.17	14.85	201.51	10800.0
APP	Bdl	32.65	12.65	73.40	Bdl	174.37	1349.6
EGB	11.10	1180.25	Bdl	237.08	0.50	198.06	25206.0
OKB	4.45	545.40	Bdl	543.33	15.00	202.06	13906.0
MDL	Bdl	440.35	6.25	153.32	Bdl	183.65	18040.0
ULWF	Bdl	298.20	0.02	216.91	Bdl	172.99	3597.6

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